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COP Estimations for High-Temperature Heat Pumps using natural refrigerants

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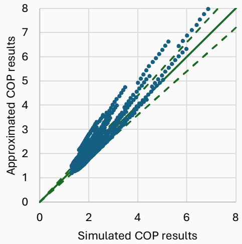
A recent study from Andersen et al. [1] established a portfolio of heat pumps that use **natural working fluids**, capable of operating efficiently over a broad range of high-temperature conditions. The study conducted simulations on a total of **1056 heat pump models under 1124 different temperature conditions,** with up to 150 K of temperature lift. As for the working fluids and heat pump configurations considered in the study, they spanned several hydrocarbons, ammonia, water, carbon dioxide, and many hydrofluoroolefins (HFOs). The configurations included diverse setups such as one-stage, two-stage, and cascade systems, capable of operating both subcritically and transcritically.

A more accurate COP model enhances the efficiency, economic viability, and environmental sustainability of heat pump systems by enabling better system design, performance prediction, and cost-effectiveness analysis. In this work, we utilize the **top performing heat pump configurations for each of the temperature conditions** simulated by Andersen et al. to fit to various **COP estimation methods**.



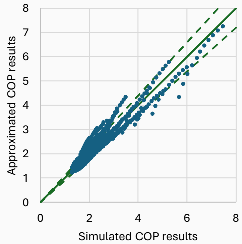
Fixed Lorenz efficiency

$$COP = \eta_{Lor} \cdot \frac{\bar{T}_{sink}}{\bar{T}_{sink} - \bar{T}_{sourc}}$$

η_{Lor}=0. 549

R^2=0.87

Widely used as a performance indicator of heat pump and refrigeration cycles, the second law efficiency allows a first approximation for heat pump performance.



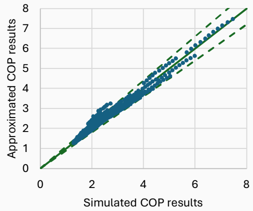
Performance models proposed by Jesper et al. [2]

$$COP = a \cdot (\bar{T}_{sink} - \bar{T}_{source} + 2 \cdot b)^{c} \cdot \left(T_{sink,out} + b\right)^{d}$$

a=28.912
b=0
c=−0.85593
d=0.287

R^2=0.93

Originally presented and fitted to 33 market-available HFC and HFO heat pumps that reach up to 100 °C with 80 K of temperature lift. The proposed parameter fit would include the natural refrigerant and a wider range of operating conditions.



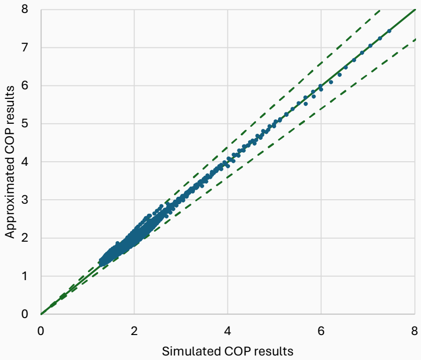
Polynomial regression of Lorenz efficiency

$$\eta_{Lor} = a \cdot T_{source,in} + b \cdot \left(T_{sink,out} - T_{source,in}\right) + c \cdot \left(T_{source,out} - T_{source,in}\right) + d \cdot \left(T_{sink,out} - T_{source,in}\right) + e$$

a=0.480802
b=−0.00011
c=−0.00847
d=0.00129
e=0.00043

R^2=0.98

A polynomial fit of the temperatures defining the inputs to the model allow for a closer approximation to the simulated results by including the temperature glide on both sink and source of the heat pump.



Performance models proposed by Jensen et al. [3]

$$\eta_{Lor} = \frac{\left(1 + \frac{A + \Delta T_{pp}}{\bar{T}_{sink}}\right) \cdot \eta_{is,c} \cdot (1 - B)}{1 + \frac{A + \frac{\left(T_{source,in} - T_{source,out}\right)}{2} + 2 \cdot \Delta T_{pp}}{\bar{T}_{sink} - \bar{T}_{source}}} + \left(1 - \eta_{is,c} - f_Q\right) \cdot \frac{\bar{T}_{sink} - \bar{T}_{source}}{\bar{T}_{sink}}$$

R^2=0.99

$$A = a \cdot \left(T_{sink,out} - T_{source,out} + 2 \cdot \Delta T_{pp}\right) + b \cdot \left(\mathrm{T_{sink,out}} - \mathrm{T_{sink,in}}\right) + \mathrm{c}$$

$$B = d \cdot \left(T_{sink,out} - T_{source,out} + 2 \cdot \Delta T_{pp}\right) + e \cdot \left(\mathrm{T_{sink,out}} - \mathrm{T_{sink,in}}\right) + \mathrm{f}$$

a=−0.402193
b=0.966630
c=−1.824054
d=−0.000158
e=−0.001581
f=0.47688

Originally presented to estimate the performance of ammonia and isobutane HTHPs, the proposed formulation by Jensen et al. includes additional parameters such as the isentropic efficiency of the compressor ($\eta_{is,c}$), the driving temperature difference with the refrigerant (ΔT_{pp}) and the heat loss factor of the compressor (f_Q).

The intricacy of this model is justified by its accuracy, establishing it as the most precise COP estimation method.

High-Temperature
Heat Pump Symposium

[1] Andersen et al. "*Selection of working fluids and heat pump cycles at high temperatures: Creating a concise technology portfolio*"
[2] Jesper et al. "*Large-scale heat pumps: Uptake and performance modelling of market-available devices*"
[3] Jensen et al. "*Heat pump COP, part 2: Generalized COP estimation of heat pump processes*"